Commercial Building Energy Alliance Technical Specification
Low-Voltage Dry-Type Distribution Transformers
Plug and Process Load Project Team
Version 1.0
April 2, 2012

Summary

This draft specification provides a description of required performance characteristics for high-efficiency Low-Voltage Dry-Type Distribution Transformers (Dry-LVDT). Commercial buildings use Dry-LVDTs as the final voltage transformation on the customer side of the utility meter. Electricity from the electrical distribution lines flows through the transformer to all building equipment. The final specification will be developed with Commercial Building Energy Alliance (CBEA) member and manufacturer input and include minimum requirements that will be of interest to a critical number of CBEA members.

This draft specification is not intended to be a comprehensive purchase specification. It is intended to supplement a purchase specification by outlining energy-related product requirements.

1. Acronyms and Definitions

Low-Voltage Dry-Type Distribution Transformers (Dry-LVDT) – a classification of distribution transformers having input and output voltages less than or equal to 600 V, and using air as a heat-exchange medium rather than oil or another liquid

Nameplate Capacity – the nominal capacity at full load for a distribution transformer as advertised by the manufacturer

Notice of Proposed Rulemaking (NOPR) – a step of the U.S. federal rulemaking process where DOE publishes the proposed regulatory language in the Federal Register for public comment

Technical Support Document (TSD) – the justification and analysis document that accompanies a NOPR

2. Specification Scope

2.1. Covered Equipment

This specification covers dry-type single-phase distribution transformers rated between 15 kVA and 333 kVA, and dry-type three-phase distribution transformers rated between 15 kVA and 1000 kVA with the following characteristics:

- The Dry-LVDTs that have input and output voltages less than or equal to 600 V.
- The Dry-LVDTs that are air-cooled and do not use oil as a coolant.

2.2. Non-Covered Equipment

This specification does not cover transformers with the following characteristics:

- Liquid-filled transformers
- Products excluded from NEMA TP 1-2002.

2.3. Relevant Codes, Standards, or Specifications

This specification builds on the existing U.S. Department of Energy (DOE) performance guidelines set forth in 77 FR 7282 [February 10, 2012]. As shown in Table 1, this CBEA specification increases the efficiency level for Dry-LVDTs above the proposed DOE standard.

Table 1: Efficiency Levels for Proposed DOE Standard and CBEA Specification

Design Line	Range of Nameplate Capacity (kVA)	Phase	Proposed Efficiency Level for DOE Standard	Efficiency Level for CBEA Specification
6	15-333 kVA	Single	Base	3
7	15-150 kVA	Three	2	4
8	225-1000 kVA	Three	2	4

Additional details on efficiency levels may be found in the DOE Distribution Transformer Notice of Public Rulemaking (NOPR) Technical Support Document (TSD) retrieved from: http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/dt_nopr_tsd_complete.pdf

3. Energy-Efficiency Requirements

3.1. Dry-LVDT Efficiency Requirements & Test Method

Products meeting this specification shall meet or exceed the efficiency levels of Table 2 when tested in accordance with DOE Test Procedure, *Appendix A to Subpart K of Part 431 – Uniform Test Method for Measuring the Energy Consumption of Distribution Transformers* [October 16, 2006].

Table 2: Minimum Efficiency Requirements (%) at 35% of Nameplate Capacity (kVA) for Dry-LVDTs Meeting this Specification

Single Phase		Three Phase	
Nameplate Capacity (kVA)	Efficiency (%) at 35% of Nameplate Capacity (kVA)	Nameplate Capacity (kVA)	Efficiency (%)at 35% of Nameplate Capacity (kVA)
15	98.41%	15	98.06%
25	98.60%	30	98.37%
37.5	98.73%	45	98.52%
50	98.82%	75	98.70%
75	98.94%	112.5	98.83%
100	99.01%	150	98.91%
167	99.13%	225	99.37%
250	99.21%	300	99.41%
333	99.27%	500	99.48%
		750	99.53%
		1000	99.56%

Question: *Research suggests that certain commercial buildings (e.g. office buildings or schools) may operate closer to 15-20% of nameplate capacity, and would benefit from Dry-LVDTs optimized for this condition. Should this specification develop Dry-LVDTs optimized for a design load of 15-20% nameplate kVA capacity? What should be the design load? Should the units be rated for two conditions, a low-load rating and the standard 35% rating?*

4. Other Requirements

4.1. Regulatory Compliance

Products meeting this specification shall comply with all applicable federal and state standards, regulations, and laws governing these types of distribution transformers. This includes all applicable safety and environmental standards.

4.2. Industry Compliance

Products that meet this specification shall comply with all applicable industry standards as set forth by ANSI, IEEE, NAMA, and others.

Question: *What industry certifications should be included in this specification? UL listing?*

Question: *Given the extended lifetime of Dry-LVDTs (25 years and greater) what would be the preferred and maximum payback period for this equipment type?*

Question: *Are there any other features that should be included in this specification, such as enclosure or noise ratings or should the specification be limited to energy performance and other critical requirements?*

5. Warranty Requirements

Products meeting this specification shall carry a warranty for a period of ten years from the date of manufacturer covering material and workmanship defect.

Question: *Is a 10 year warranty appropriate for this type of equipment? What should be stipulated in the warranty for customers, for manufacturers?*

6. References

a. DOE 77 FR 7282 [February 10, 2012], Distribution Transformers – Notice of Proposed Rulemaking

b. NEMA TP 1-2002, Guide for Determining Energy Efficiency for Distribution Transformers

Appendix A: Example Full System Specification

Note: The full system specification will be developed once energy guidelines are finalized.

Appendix B: Accompanying Document and Energy Savings Analysis

Note: Included as an attachment

Sources: Eaton, GE, Appliance-Standards.org

Distribution Transformers

Supplementary Information for Technical Specification

April 2, 2012

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With assistance from CBEA members, DOE is pursuing technology specifications to help pull innovative, energy-saving technologies to market.

- This report supplements the technology specification for **Low-Voltage Dry-Type Distribution Transformers (Dry-LVDTs).**
- Distribution transformers are found on commercial buildings in many CBEA sectors including hospitals, retail, warehousing, offices, etc.
- All electricity provided to the building runs through the dry-LVDT, so small gains in efficiency can have large impacts on total energy used.

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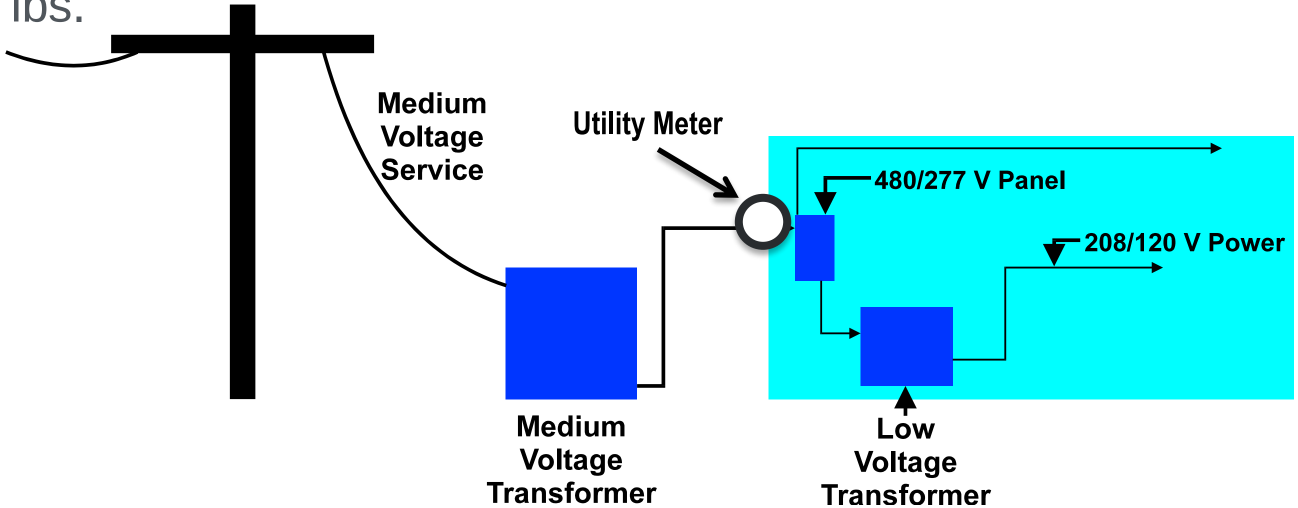
Commercial buildings use Dry-LVDTs as the final voltage transformation on the customer side of the meter.

- Common characteristics for Dry-LVDTs include:
  - Rated between 15 kVA and 333 kVA for single phase or rated between 15 kVA and 1000 kVA for three phase
  - Input and output voltages less than or equal to 600V
    - Typically 480, 277, 240, 208, or 120 V
  - Air-cooled and do not use oil as a coolant
  - Depending on capacity and design, Dry-LVDTs weigh between 200-3000 lbs.



Source: CEE

For Dry-LVDTs, the efficiency metric is based on the nameplate capacity, load losses, and core losses.

- The efficiency metric is calculated using a 35% nameplate capacity, which is the industry assumption for a typical loading of a commercial building.
- Dry-LVDT efficiency calculated by the following equation:

$$\%E = \frac{100 \times (P \times kVA \times 1000)}{(P \times kVA \times 1000) + NL + (LL \times P^2 \times T)}$$

Where:

- P = 0.35 for Dry-LVDTs
- kVA = nameplate kVA capacity
- NL = No load (core) loss at 20˚C in watts
- LL = Load loss at reference load temperature per C57.12.01, in watts
- T = Load loss temperature correction factor at 75˚C.

The existing DOE test procedure and minimum efficiency standard are based on NEMA TP 1-2002.

Dry-LVDT– Existing DOE Min Efficiency (%) at 35% of Nameplate Capacity (kVA)

Single Phase		Three Phase	
Nameplate Capacity (kVA)	Efficiency (%) at 35% of Nameplate Capacity	Nameplate Capacity (kVA)	Efficiency (%) at 35% of Nameplate Capacity
15	97.7%	15	97.0%
25	98.0%	30	97.5%
37.5	98.2%	45	97.7%
50	98.3%	75	98.0%
75	98.5%	112.5	98.2%
100	98.6%	150	98.3%
167	98.7%	225	98.5%
250	98.8%	300	98.6%
333	98.9%	500	98.7%
		750	98.8%
		1000	98.9%

High-efficiency Dry-LVDT standards or specifications exist from a number of entities.

- DOE Distribution Transformer Notice of Public Rulemaking (NOPR) - 77 FR 7282 [February 10, 2012]
  - The NOPR proposes new efficiency standards that would take effect January 1, 2016.
  - The CBEA technology specification is based on the NOPR
- NEMA Premium Efficiency Transformer Program
  - Voluntary manufacturer-driven program launched in 2010.
  - Efficiency levels are 0-30% more efficient than DOE NOPR levels
  - Multiple manufacturers offer NEMA Premium equipment.
- CEE Commercial and Industrial Distribution Transformer Initiative
  - Voluntary utility-driven program launched in 2011.
  - Utilizes NOPR Efficiency Level 5
  - Efficiency levels are 30-40% more efficient than DOE NOPR levels

Most Dry-LVDTs installed today equal current DOE minimum efficiency standards.

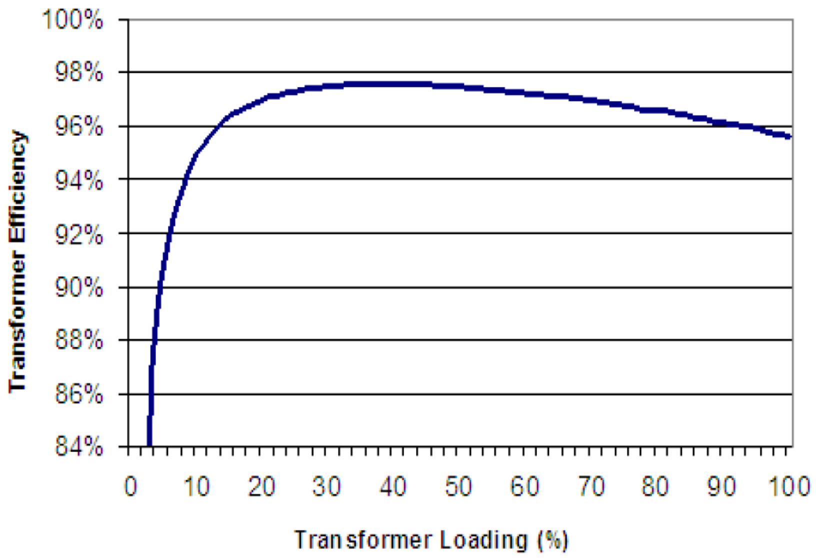
- In 2009, Dry-LVDT shipments were on the order of 225,000 units with a total rated capacity around 16,400,000 kVA*.
  - 90% of Dry-LVDT shipments were three phase
  - Dry-LVDTs below 300 kVA are typically stock items, with higher capacities built-to spec.
- Only about 5% of Dry-LVDT shipments meet NEMA Premium levels**.
  - Currently only one manufacturer stocks NEMA Premium Dry-LVDTs in the most common capacities of 40, 75, 112.5, and 150 kVA.
  - Multiple manufacturers offer high-efficiency Dry-LVDTs built-to-spec.

•DOE. 2012. “Distribution Transformers – Notice of Proposed Rulemaking.” Energy Conservation Standards Rulemaking.

**Burgess, Jess. 2011. “Commercial and Industrial Distribution Transformers Initiative.” Consortium for Energy Efficiency. November 9, 2011.

High-efficiency Dry-LVDTs improve performance by optimizing no-load and load losses for a given design condition (typically 35% of nameplate capacity).

- Two types of losses determine Dry-LVDT efficiency:
  - No-load (core) losses – caused by core hysteresis and eddy currents present at zero load, remain virtually constant with loading.
  - Load (winding) losses – caused primarily by the resistance of the winding material, increase with square of applied load.



Source: DOE NOPR TSD

Design changes that reduce no-load losses often increase load losses, and vice versa.

- Table 3.10.1 from the NOPR Technical Support Document describes this efficiency tradeoff.

Table 3.10.1 Options and Impacts of Increasing Transformer Efficiency

	No-load losses	Load losses	Cost impact
To decrease no-load losses			
Use lower-loss core materials	Lower	No change*	Higher
Decrease flux density by:			
(a) Increasing core cross-sectional area (CSA)	Lower	Higher	Higher
(b) Decreasing volts per turn	Lower	Higher	Higher
Decrease flux path length by decreasing conductor CSA	Lower	Higher	Lower
Use 120° symmetry in three-phase cores**	Lower	No change	TBD
To decrease load losses			
Use lower-loss conductor material	No change	Lower	Higher
Decrease current density by increasing conductor CSA	Higher	Lower	Higher
Decrease current path length by:			
(a) Decreasing core CSA	Higher	Lower	Lower
(b) Increasing volts per turn	Higher	Lower	Lower

* Amorphous-core materials would result in higher load losses because flux density drops, requiring a larger core volume.

** Sometimes referred to as a "hexa-transformer" design.

Manufacturers have multiple pathways to optimize efficiency for Dry-LVDTs.

- Changing the following parameters affects efficiency:
  - Type of core steel (M2, M3, M4, M5, M6, amorphous, etc.)
  - Winding materials (copper or aluminum)
  - Core configurations (shell or core-type).

- Each manufacturers will incorporate different features into their designs to meet the efficiency requirements.

Maximum efficiency occurs when the Dry-LVDT is optimized for the most common building load.

- Industry designs and rates Dry-LVDTs for 35% of nameplate capacity to account for the typical commercial building load.
- Research suggest buildings may operate closer to 15-20% of nameplate capacity.*
  - Buildings operating at lower load have greater losses using Dry-LVDTs designed for the 35% rating requirement.
  - Proposed DOE standard will continue 35% rating requirement.
  - A number of industry stakeholders have shown interest in a low-load Dry-LVDT.
- Depending on CBEA interest, this specification could optimize efficiency at 15-20% of nameplate capacity or at multiple points.

* NEEP. 1999. "Metered Load Factors for Low-Voltage, Dry-Type Transformers in Commercial, Industrial and Public Buildings.

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The CBEA specification increases the efficiency level for Dry-LVDTs above the proposed DOE standard.

Efficiency Levels for Proposed DOE Standard and CBEA Specification

Design Line	Range of Nameplate Capacities (kVA)	Phase	Proposed Efficiency Level for DOE Standard	**Efficiency Level for CBEA Specification**
6	15-333 kVA	Single	Base	3
7	15-150 kVA	Three	2	4
8	225-1000 kVA	Three	2	4

- Design Line refers to Dry-LVDT equipment classes based on similar principles of design and construction.
- Efficiency Level refers to an set of design criteria to achieve increased efficiency for a design line.

Additional details on efficiency levels may be found in the DOE Distribution Transformer Notice of Public Rulemaking (NOPR) Technical Support Document (TSD) retrieved from: http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/dt_nopr_tsd_complete.pdf

This specification reduces Dry-LVDT losses by 15-40% over the proposed DOE standard.

Single-Phase Transformers – Reduction of Losses (%) at 35% of Nameplate Capacity (kVA)

Nameplate Capacity (kVA)	Reduction of Losses (%)
15	31%
25	30%
37.5	30%
50	31%
75	29%
100	29%
167	33%
250	34%
333	33%

Three-Phase Transformers – Reduction of Losses (%) at 35% of Nameplate Capacity (kVA)

Nameplate Capacity (kVA)	Reduction of Losses (%)
15	15%
30	15%
45	15%
75	15%
112.5	15%
150	15%
225	40%
300	40%
500	40%
750	40%
1000	40%

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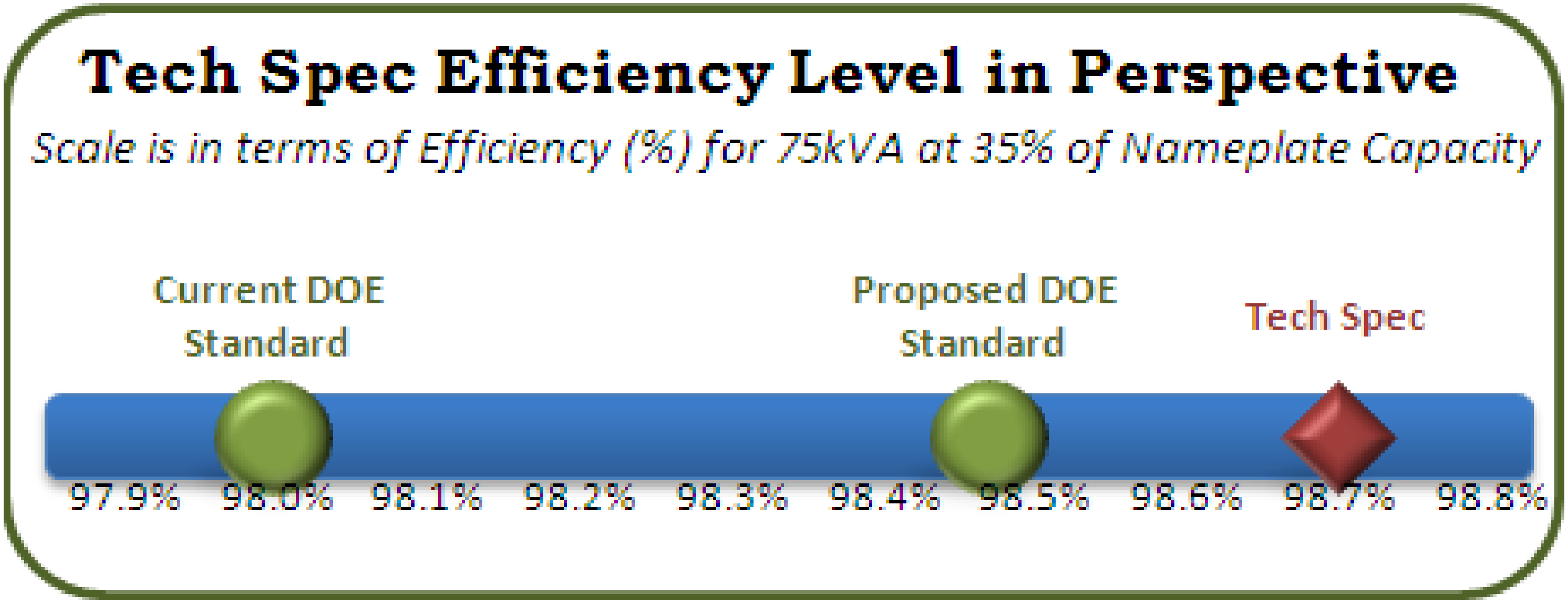
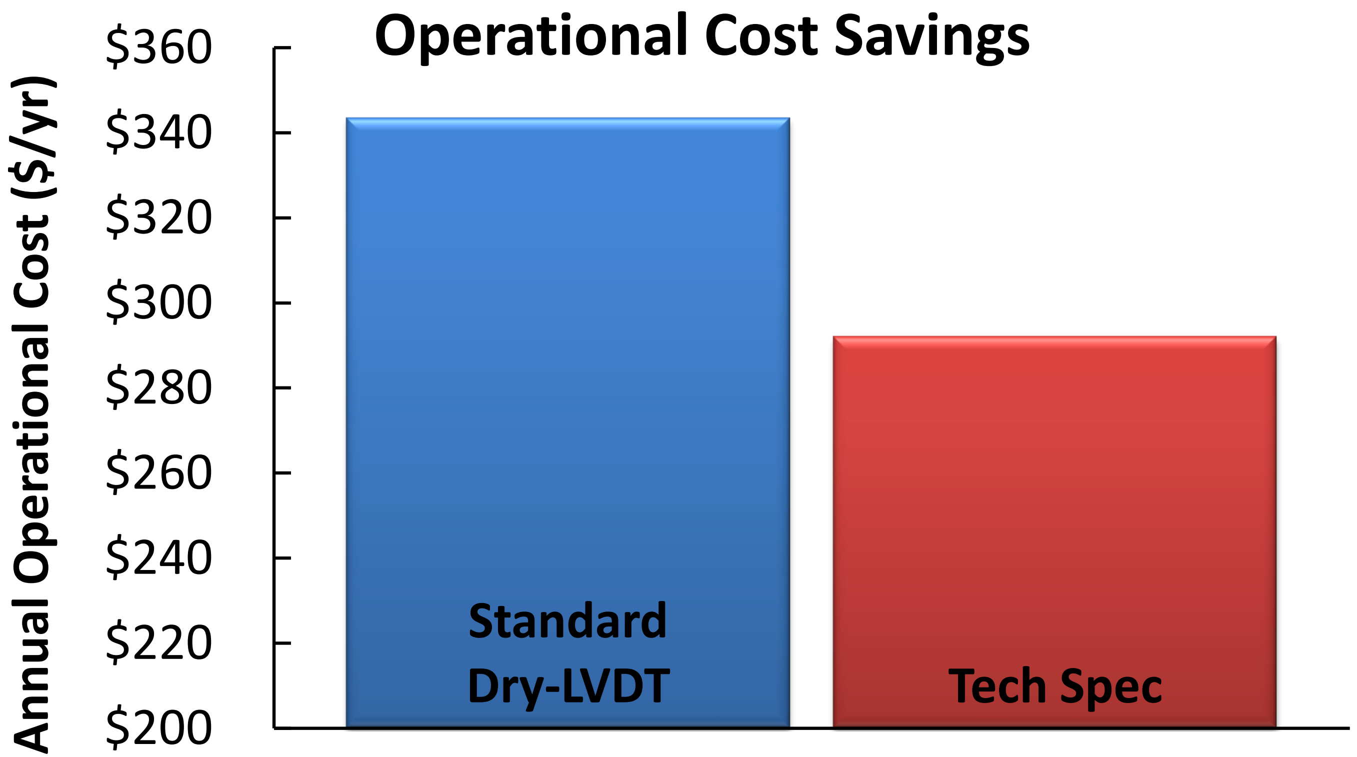
Dry-LVDTs meeting this specification would have higher efficiency than what is typically installed today.

– Majority of shipments meet minimum standards.



Dry-LVDTs meeting this specification would save over $50 per year compared to standard-efficiency units.



Assuming 75 kVA capacity Dry-LVDT at 35% load for 8,760 hrs/yr at $0.098/kWh

Based on a simple payback of three years, spec'd Dry-LVDTs could be allowed moderate price premiums.

- The table below provides the allowable price premium for an average Dry-LVDT meeting this specification over the proposed DOE standard that results in a three year simple payback.
  - Assuming 35% load at nameplate capacity for 8760 hours/year at $.10/kWh

Allowable Price Premium for Representative Dry-LVDTs ($)

Nameplate Capacity (kVA) / Phase	Energy Savings of CBEA Specification (kWh/yr)	Allowable Price Premium for 3-year Payback ($)
25 kVA / Single	460	$138
75 kVA / Three	529	$159
300 kVA / Three	3587	$1076